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REVIEW ARTICLE

Automobiles Shift from Chemical Energy to Electric Energy

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ABSTRACT

Global Warming is a major concern of the entire world today and climate control is taken as a major initiative by the world to save nature and the world from pollutants and automobile emission. Due to an increase in the global warming, the coastal areas such as Bangladesh, Kakinada and others will vanish in the near future if today's emissions continue. Automobile emissions are one of the major sources of global warming due to the chemical conversion of energy. The solution for this disaster is to depend on alternative sources of energy and components such as electricity, electronic components, electric automations and machines. The use of electric cars, electric motors, inverters and the smart differentials make automobiles viable; the only restriction is the cost space and weight of the batteries. The Li-Ion cells are packed to provide power and are most used today in electrical vehicles. In this article the basic use of Li-Ion cells, their packaging, methods for charging for electric vehicles are discussed.

Keywords: Electrical Vehicles, Li Ion Batteries, Global Warming, Electric Automobiles.

1. INTRODUCTION

Mechanical Engineering took a leap forward in providing transportation facilities making life faster and the reach of space wider. Technology grew as petrol cars and Diesel cars grew with German, French, Italian and English cars leading, initially taken over by American manufacturers, Ford, Chrysler and others, occupying cities and States like Michigan, Detroit to take the American economy to its peak. Since World War II, the need for Energy efficiency, cost, quality, custom made designs introduced Toyota and other Japanese manufacturers to slowly creep into the American superiority in the automobile market and made its presence felt gradually, but surely. Due to their cheap labour and Total Quality Management drive, the other East Asian countries such as South Korea and China produced cars which are cheaper, more efficient and reliable in giving better mileage.

The economic situation was driven by the availability of petrochemical minerals since 1980s; and, the Middle East countries, rich in petroleum reserves, ruled the world since 1980s. Though the reserves are depleting, the automobile industry is still growing because some developing countries like China, India, Brazil and others have also started to use auto transportation for goods and people in support of their growing economy. The result is global warming; the carbon compounds CO, CO_2 and SO_2 have been identified as eco disasters. As

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industrial pollution was seen as a less controllable evil and with solar energy and other non renewable sources like wind energy for generation of electrical energy available, the smart engineers have started focusing on electrical cars.

The electrical cars were present worldwide; with Indian industry having seen the unsuccessful launch of Reva, an electrical car, the real leap occurred in 2003 with Tesla Foundation release of Tesla Roadster in 2008. A 400km ride, assured by the charge, was having a good start in sales; and with better designs from their R&D, led to Model S, (Rs 4.8 million) in 2012 followed by Model X (Rs 5.5 million), as in Figure 1, later to add Model 3 Sedan. These models will reach the Indian market by 2018 to challenge BMW, Mercedes, Audi A4, Jaguar XF etc.

This paper gives a brief note on these models and some aspects of the Electrical cars, with emphasis on the energy storing devices led by Lithium Ion Battery banks to provide the energy required. With the related removal of the engine and long transmission lines from the front, the new automobiles have an undercarriage of electric storage supply through the inverter to the electric induction motors connected to axle through a gear system reducing the weight and providing more controlled efficient drive in the range of 0 to 8000 RPM consistently. The challenge is the cost of the battery bank which will be the focus for cost reduction and may be for better alternatives in size and capacity. The focus of this paper is also on general overall electric car followed by the specifics of the Lithium Ion batteries.

Figure 1.Tesla Model X, From Net.

2.1 Lithium Ion Rechargeable Batteries

Apart from the Automobile Industry like bicycles, bikes and cars, these batteries are normally used in many electronic devices, emergency lamps, street lights, power equipment like hand drill tools, medical test equipment, communication devices, toys and equipments of play games, education aids like projectors; in fact, all the appliances which may require power for their functioning can use these batteries. A typical battery used in Laptops or tablets is shown in Figure 2a. Figure 2b shows the battery in Tesla Model S; these are cylindrical batteries for an ease in production though there will be a loss of space if they are combined in a bank. A cubic or hexagonal prism type is more economical space-wise since space can be optimised as in Bee hives or in metallurgical lattice formation of atoms. This is an area for research and Technology. The size of the battery is defined in terms of its diameter, say for a 650mAh capacity battery working with a 3.7V difference in potential; the diameter of the battery would be 12.9mm and for a battery of 1800mAh capacity working at a voltage of 3.9V, the diameter would be 18.0mm. The tolerance on the diameter would be .05mm.

Figure 2a Li Ion for Lap tops

Figure 2b Used in Notebooks and Tesla Model S

Lithium Ion battery is most efficient among all the battery types with 90-100% efficiency. Energy storage density is about 75 to 200 Wh/kg, round trip efficiency of <50%, durability of 5 to 15 years, can be recharged 10,000 times and should be recharged in moderate temperatures, between 0 and 45 C^o [1, 2, 3]. There

have been occurrences of bursts and electric fires with Li-Ion batteries [4, 5]; presently safety fuses in circuits or in the connecting wires are provided to counter this occurrence.

A typical Lithium Ion battery holds 800mAh and 3.7V of electric power; if it discharges 800mA of current for 1 hour between terminals voltage of 3.7V, then the battery gets completely drained of its energy and needs to be recharged. They need to be recharged either by CC (constant current) method or by CV (Constant Voltage) method. They can generally be recycled about 1000 times. That means they can run continuously for about 1000hrs. If applied to a Car which is on road for 5Hrs a day on an average; then it will last 200 days. But in India about 3 hours run a day is average in the City and would last a year. This means there would be a need of the expensive batteries every year. At today's petrol price if about 10 litres of petrol at Rs 750 is used per day for a year, it would cost about Rs 2, 25, 000. The cost of replacement + battery charging would add on to this. If the Solar power is used for this recharge, the Green ECO power generation would be an advantage. For more relaxed users driving cars for about half an hour every day, these batteries may last for 5 years. It would be nice to save money proportionately for re-buying at the end of the battery life. Recharge is generally done at constant 0.2 amps or at a Constant Voltage 4.2V with a set of cut-off amperes. If it is used at lower voltages, higher current can be drawn from the battery; but, there is a limit of 800mAh maximum from such batteries.

2.2 Making Lithium Ion Batteries

These are secondary cells that can be recharged. The materials required for batteries consist of Electrolytes, conducting salts, electrode materials and additives provided by agencies like IOLITEC. They can offer a series of standard electrolytes, ionic liquids, lithium salts and interesting electrode materials, like grapheme or carbon nanotubes, for R&D use.

- Electrolytes: lithium-sulphur cells Lithium-metal, Metal-air (Zn, Al, Si, Li), Electrolytes for metal-air cells (Li, Zn, Al)
- Polymer electrolytes ("Ionomers")
- Electrode materials (carbon nanotubes, graphene)
- Filler materials

Electrolytes for Batteries

In batteries, electrochemical processes are responsible for storage and release of electric energy (charging and discharging). To transport the electric charge between the electrodes, electrolytes are necessary. Electrolytes can be liquid, but polymer- or solid-state electrolytes exist. Ionic liquids are interesting electrolytes for a series of electro-chemical cells, due to their outstanding properties such as the following:

- High electrochemical stability against reduction and oxidation (wide electrochemical window)
- Electric conductivity: for pure ionic liquids lies at up to 27 ms/cm at 25^{o}C, for mixtures it can reach up to 70 ms/cm.
- Thermal stability
- Low vapour pressure
- In flammability

There were occurrences of explosions with internal pressure built up development of special electrolytes is required. Nowadays, the most widely used conducting salt in lithium-ion batteries is lithium hexafluorophosphate ($LiPF_6$). Lithium bis (trifluoromethylsulfonyl) amide (LiBTA), however, is an interesting alternative.

Electrode materials: Carbon-nanotubes and graphene

For some time now, the interest for carbon allotropes, like carbon nanotubes (CNT) and graphene has grown very strong and has given inspiration for numerous new research fields. Within the framework of European science support institutions, the research on graphene has its own dedicated program. CNT and graphene have the potential as new types of electrode materials.

Filler materials

Filler materials, as additives to electrolytes, can perform various tasks. Composites, made from ionic liquids and nano materials, can improve the cyclability of batteries. Nanomaterials, such as barium titanate, find their use as fillers.

2.3 Combining batteries to provide the end requirement

Batteries are required for remotes when two might be used together up to the car bank of 8000 batteries; and, proper clamping and connecting them in a series or parallel or a combination of both as per the Kirchhoff's laws is one of the basic

requirements of electrical engineers designing power source for equipment. Four batteries in Figure 3 depend on the application which requires a potential difference of V volts and has to deliver power with some current, I amps giving a power of W watts. This, along with Ohms Law, defines the circuits. These basic laws of electric circuits are applicable for both AC & DC circuits. Ohm's law tells us that when current I flows through a circuit with a voltage difference of V Volts, the flow of current is restricted by the resistance of the conductor, called Ω; and, the relation of the current and voltage is a direct relation.

$$V = I\Omega \qquad (1)$$

The law of power of circuit gives relation of power voltage and current assuming there is no phase difference between the voltage and current:

$$W = VI \qquad (2)$$

Figure 3 Four batteries for fixing tool

In 1845 Gustav Kirchhoff defined two laws of electrical circuits for current and potential difference as occurs in the joints of electrical circuits. The first law relates to the current flowing through the same node as given here Equation (3):

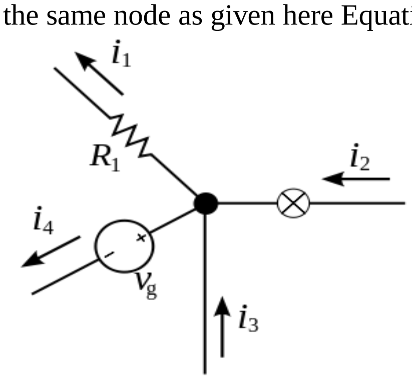

Figure 4 Law of current flow

$$\sum_j^n = Ij = 0 \qquad (3)$$

Consider that the currents flowing in as positive and flowing out as negative, under the same voltage, Vg, as shown in Figure 4. All the currents are below in Equation (4).

$$I_1 + I_4 = I_2 + I_3 \qquad (4)$$

Similarly, for combining voltages in the loop of Figure 5, of flow of current through a circuit, the input driving voltage Vg to three resistances R_1, R_2 & R_3, the current passing through these voltages will be the same, say I:

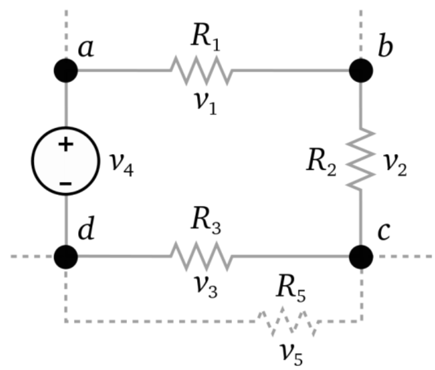

Figure 5 Law of Voltage drops in a circuit

Kirchhoff's second law, law of loop or conservation of emf, states that the sum of all the voltages is zero in a closed looped circuit as in Equation (5).

$$\sum_j^n = Vj = 0 \qquad (5)$$

Or if V4= driving emf, the electro motive force, is equal to the voltages across all resistances in the circuit, balance of voltage is given in Equation (6).

$$V_4 = V_1 + V_2 + V_3 \qquad (6)$$

The combinations of batteries can be analysed with the above rules along with the rules of resistances: Resistances in series add up to give total equivalent resistance R, as given in Equation (7).

$$R = R_1 + R_2 + R_3 \qquad (7)$$

For the four batteries shown in Figure 3, as here $V = V_1 + V_2 + V_3 + V_4 or V = 4*3.7 = 14.8V$, emf current passing through each battery is the same say, 800mA. The total power is also as follows: $VI = V_1I + V_2I + V_3I + V_3I$

Similarly, resistances in parallel have an inverse relationship with the equivalent resistance R, as given in Equation (8):

$$\frac{1}{R}=\frac{1}{R_1}+\frac{2}{R_2}+\frac{1}{R_3} \qquad (8)$$

These rules are used to design massive banks of batteries. If the four batteries shown in Figure 3 are connected in parallel, all of them will have the same voltage 3.7V; but, the current drawn will be 4*800 =3200mAh.

Figure 6 Tesla Li-Ion battery power bank

Tesla Model S has a solar power charging a Li Ion storage of about 7000 cells. There are 16 modules which are delivering the power at 400VDC. The cells are connected to the bus by thin electric wires and a water cooling system. The weight of this cell bank and its cost are the areas of research for improvement. The total package has about 115 in series to get the required voltage and about 61 in parallel to get the required current. When divided among the 16 modules, the current rows become Each module whose configuration is shown in Figure 7; as a representative model, the actual power pack has about 30 in series to maintain the voltage; they form the columns of the package and the 16 connected parallels to obtain the required current. Further the 16 modules output - both positive and negative - are connected to get the total power for the electrical vehicle.

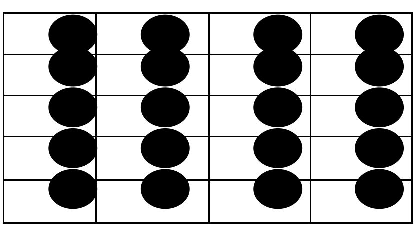

Figure 7A Typical Module of Batteries

When all the batteries are connected, it will be required to manage them during the processes of charging and discharging. A BMS, Figure 8, shows the Battery Management System for a car power pack. It monitors the charge and discharge and assures the safety of the cells, power pack and the car. It makes sure that there is no excess or less of charge and gives reliability to the eclectic system.

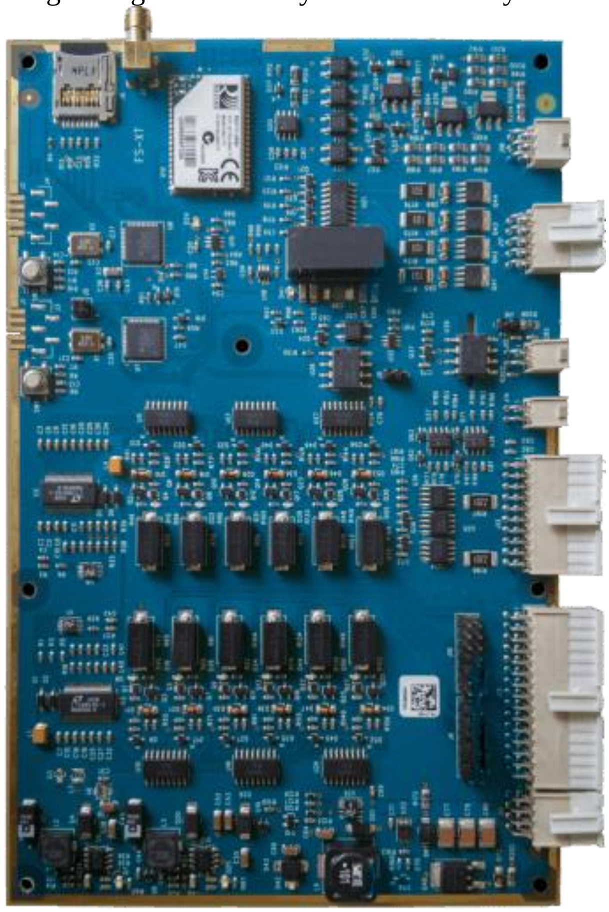

Figure 8 A Battery Management System

2.4 Electric Charging Stations:

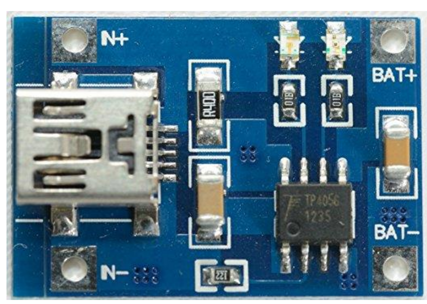

Figure 9 Individual Charging circuit

The Charger, Shown in Figure 9, is a 1A charger for Lithium Ion battery costing Rs. 175 on the net. The cost of 2 Lithium ion batteries of LG make is Rs. 425 with 2000mAh rating.

Charging pile with multiple protection function, input and output with double safety protection measures, charging real-time monitoring of the connection of the charging cable status, connection abnormalities immediately terminate the charge to ensure that the charging process is safe for people and vehicles.

Li Ion Cells discharge power by movement of electrons from negative to positive electrodes [6].

During charging, an external electrical power source (the charging circuit) applies an excess of voltage (a higher voltage of the same polarity than the battery produces), forcing a charging current to flow within the battery from the positive to the negative electrode, i.e. in the reverse direction of a discharge current under the normal conditions. [The conditions of good storage are given in references 7 and 8.] The lithium ions then migrate from the positive to the negative electrode, where they become embedded in the porous electrode material in a process known as Intercalation. This review investigated, with some innovative novel ideas, on the energy storage technology, lithium-ion storage batteries that satisfy the environmental needs with higher efficiency and about all the other aspects required [9 and 10].

The charging procedures for single Li-Ion cells, and complete Li-ion batteries, are slightly different.

- Single Li-Ion cell is charged in two stages:

1. Constant Current (CC)
2. Constant Voltage (CV)

- A Li-ion battery (a set of Li-Ion cells in series) is charged in three stages:

1. Constant Current
2. Balance (not required once battery is balanced)
3. Constant Voltage

During the constant current phase, the charger applies a constant current to the battery at a steadily increasing voltage, until the voltage limit per cell is reached.

During the balance phase, the charger reduces the charging current and the individual cells are brought to the same level by a balancing circuit, when the battery is balanced. Some fast chargers skip this stage. Some chargers accomplish the balance by charging each cell independently. During the constant voltage phase, the charger applies a voltage equal to the maximum cell voltage times the number of cells in series to the battery, as the current gradually declines towards 0, until the current is below a set threshold of about 3% of initial constant charge current. Any failure to follow the current and voltage limitations can result in an explosion.

Periodic topping charge is about once per 500 hours. Top charging is recommended to be initiated when the voltage goes below 4.05 V/cell. Figure 10 shows a charging station for car batteries; as the charging would take time and as it is difficult to stay at station, there should be a quick replacement of power packs by removing electrical plug, unclamping the tray of batteries and replacing with charged ones. This activity needs to be established between the customers and charging stations and would not require customers to plan to buy new set of batteries and the charging station of assured customers. As the price of batteries presently $275/kWh is expected to come down to $75/ kWh in the long run, these automobiles would reach common men, say by 2030.

Figure 10 A Public Charging Unit.

A good possibility will be solar generators linked to the charging units which should have charged power packs, to be quickly changed as the customer comes for charging with a permanent

commercial agreement with mutually agreeable terms.

Conclusion

Electrical cars are replacing cars using Petrol and Diesel engines. The thermo chemical power to mechanical power used today will be replaced by Electrical to Mechanical power. Led by Tesla, it was followed by Mercedes and Mahindra in India; these new cars are getting into market and will dominate the automobile scenario by 2030. The major weight, volume and cost contribution for these cars are the battery power packs. At present, Li Ion batteries are available at $250 per kWh and are expected to reduce to $75 by 2030. A focussed effort will make these more ECO friendly cars suitable for the world. This article is an introduction to this evolving technology making aware of the basics of the use of Li Ion batteries for automobiles, apart from the other applications which are already in place.

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